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ORIGINAL PAPER

Does litterfall from native trees support rainfed agriculture? Analysis of *Ficus* trees in agroforestry systems of southern dry agroclimatic zone of Karnataka, southern India

B. Dhanya • Syam Viswanath • Seema Purushothaman

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Abstract: Trees of the genus *Ficus*, integral components of indigenous rainfed agro-ecosystems of the southern dry agro-climatic zone of Karnataka, southern India, have traditionally been associated with the ecological service of soil quality enhancement in addition to various direct use benefits. We assessed the soil enrichment service of *Ficus benghalensis* L. a common *Ficus* species in these agroforestry systems, by quantifying nutrient return via litter fall. Litterfall estimation and chemical analysis of litter showed that *F. benghalensis* trees produce 3,512 $kg\cdot ha^{-1}$ of litter annually which, on decomposition, can satisfy up to 76.70 % of N, 20.24% of P and 67.76% of K requirements of dryland crops annually per hectare. This can lead to an avoided cost of compost of US $ 36.46 $ha^{-1}\cdot a^{-1}$ in dryland farming systems. The slow rate of decay of *Ficus* litter, as revealed in litter decomposition studies indicates its potential as ideal mulch for dryland soils. We discuss the complementarity between *Ficus* litterfall and cropping patterns in Mandya, and its implications for rainfed agricultural systems.

Keywords: soil enrichment; litter traps; litter bags; litter decomposition; complementarity

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B. Dhanya (✉)
Tree improvement and Propagation Division, Institute of Wood Science and Technology, Malleswaram, Bangalore, Karnataka-560003, India; College of Agriculture, University of Agricultural Sciences, PB No.329, Raichur, Karnataka-584102, India. Phone: +91-9844316406
E-mail: krupaias@gmail.com

Syam Viswanath
Tree improvement and Propagation Division, Institute of Wood Science and Technology, Malleswaram, Bangalore, Karnataka-560003, India.

Seema Purushothaman
Centre for Environment and Development, Ashoka Trust for Research in Ecology and the Environment, Royal Enclave, Srirampura, Jakkur, Bangalore, Karnataka- 560064, India.

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Introduction

The southern dry agro-climatic zone of Karnataka state of south India, especially Mandya district, harbours a remarkable abundance and diversity of trees of the genus *Ficus* in association with field crops of millets, maize, pulses and oilseeds in rainfed farmlands. *F. benghalensis* L. is the major species of *Ficus* grown in these agroforestry systems, followed by *F. religiosa* L., *F. amplissima* Sm., *F. virens* Aiton, *F. racemosa* L., *F. mysorensis* var. *pubescens* Roth etc. (Dhanya et al. 2010). Preliminary farmer interviews and discussions held in villages of Mandya revealed *Ficus* trees to be crucial for maintaining the productivity of dryland agricultural systems by virtue of various ecological services, in addition to multiple direct benefits of fodder, fuel wood, shade and small timber. The value of *Ficus* trees in enriching soil quality through litterfall was highlighted by farmers. Presence of *Ficus* trees in dryland cropping fields is perceived to reduce fertiliser usage: Mandya farmers who have limited financial resources to purchase chemical fertilisers plough in *Ficus* litter as a source of organic input for crops. However scientific studies on litterfall and litter decomposition of *Ficus* species are few and deal with *Ficus* in forest ecosystems (Pragasan and Parthasarathy 2005), or in other regions or agroclimatic zones (Semwal et al. 2005; Mubarak et al. 2008). Quantification of litter fall and litter decomposition rate of *Ficus* species in agroforestry systems of semiarid tropical zones is lacking. We undertook a detailed investigation to assess nutrient return through *Ficus benghalensis* litterfall and its subsequent decomposition in rainfed farmlands of Mandya. Our objective was to understand the impact of *Ficus* tree species on soil organic matter status and nutrient availability.

Materials and methods

Study area

Mandya district covers 4,961 km^2 of plains in the southern dry climatic zone of Karnataka at elevations ranging from 757–909 m above mean sea level. We selected a plot of 0.8 ha area for litter studies in Mandya, located at 12°29′ N latitude and 76°59′ E longitude. *F. benghalensis* trees were grown here in association with finger millet (*Eleusine coracana* (L.) Gaertn.) and horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.). The mean daily minimum and maximum temperatures for 2009 were 19°C and 31.5°C, respectively and total annual rainfall for the year was 800 mm, with most of the rain received during the pre-monsoon month of May and monsoon months of June – September. Soil at the study site was red, slightly acidic (pH of 6.5), and the texture ranged from gravelly sandy clay to sandy clay loam. Organic carbon content of soil (0–15 cm depth) was high at 1.33%, available N content was 204.3 kg·ha^{-1}, available P, 2.5 kg·ha^{-1} and available K, 642.2 kg·ha^{-1}. Exchangeable Ca and Mg were high at 2102.1 µg·L^{-1} and 420.4 µg·L^{-1} respectively and available S had a moderate value of 47.9 µg·L^{-1} (Dhanya 2011).

Litterfall estimation

Ten *F. benghalensis* trees of average size (average girth at breast height (gbh) of 1.88 m, average crown height of 15 m and average crown diameter of 20 m) and representative of trees usually retained in fields were selected for litter experiments. Thirty semi-permanent square litter trap structures (Proctor 1983; Tanner and Kapos 1992) were constructed using brick and mortar at the rate of two to four per tree to cover at least one percent of the canopy area in all directions. Each trap had a height of 0.75 m and nylon net with collection area of 1 m^2 was inserted at a height 0.25 m from the base in order to permit drainage of water and to avoid action of soil fauna, soil splash, and grazing livestock. The contents of the traps were collected at monthly intervals, oven dried at 70°C till constant weights were obtained and then segregated into leaves, twigs and flowers, fruits and buds, and weighed. Mean litter production was computed component-wise on a unit area basis for each tree and each month from April 2009 to March 2010 and monthly litterfall data were summed to obtain the annual litter yield.

Chemical analysis of litter

Duplicate samples of leaf, twig and flower, fruit and bud components from the pooled monthly litter collections from traps were analysed for total N (micro-Kjeldahl method in Kel Plus – KES 6L Auto distillation Unit), P (vanado- molybdo phosphoric yellow colour method), and K (flame photometry using Elico-CL 378 flame photometer) following Jackson (1973) to characterise seasonal variation in litter nutrient concentration. Nutrient additions through litter were computed using the data on monthly litterfall and nutrient contents (Jamaludheen and Kumar 1999).

Litter decomposition studies

We initiated litter decomposition studies on the same site as the litter traps during the last week of March 2009, employing the standard litterbag technique of Anderson and Ingram (1993). Nylon bags of size 30 cm × 20 cm and mesh size 2 mm were filled with 20 g of freshly fallen/senescent foliage of *F. benghalensis* that was shade dried for 48 h. Sixty litter bags were buried in the soil (subsurface treatment) and an equal number was placed on the soil surface (surface treatment) to study the effect of placement on decomposition under *F. benghalensis* tree canopy. Samples of air dried litter were also kept apart for analysis of N, C (Walkley and Black method), lignin [Klason's procedure (Rowell et al. 2005)] and total phenol content [Folin- Ciocalteau reagent method (Sadasivam and Manickam 1992)].

Five samples each were drawn at monthly intervals from surface and subsurface treatments for one year from April 2009 to March 2010. Residual litter mass from bags was washed after excluding fine roots and macro-arthropods penetrating the mesh, oven dried at 70°C and weighed. Decomposition rates of the substrates were estimated from the first order exponential equation,

$$e^{-kt} = \frac{L_R}{L_1} \tag{1}$$

where, k is decomposition rate per year, t is the time interval of sampling L_R expressed in years, L_R is the litter weight remaining at a given time and L_1 is the initial litter weight at time zero (Mugendi and Nair 1997). Half-life period ($t_{0.5}$) of the decomposing litter samples was estimated from k values using the equation,

$$t_{0.5} = \frac{0.693}{-k} \tag{2}$$

Statistical analyses

Data on nutrient contents of litter collected monthly in the traps and residual litter mass in bags after one year of decomposition were statistically analysed using One Way ANOVA and Two Way ANOVA techniques, respectively, in Sigmastat 3.5 statistical software and Fisher's Least Square Difference (LSD) values were calculated.

Results and discussion

Quantity and pattern of litterfall

Annually, around 3,512 kg·ha^{-1} of litter was dropped by *F. benghalensis* trees at 16 trees·ha^{-1}, the average density at which trees are maintained in farmlands of Mandya. Leaf litter constituted 60% of total litterfall (2,120 kg·ha^{-1}) and the balance (1,391

kg·ha^{-1}) was contributed by others including twigs and reproductive parts. *F. benghalensis* in agroforestry systems of Mandya produced an amount of litter higher than that reported for traditional agroforests [1406 kg·ha^{-1}·a^{-1} (Deb et al. 2008)] and equivalent to the lower range reported for tropical wood lots [3.42 Mg·ha^{-1}·a^{-1} (Jamaludheen and Kumar 1999)]. Quantity of annual litter fall per *F. benghalensis* tree (219. 44 kg·tree^{-1}·a^{-1}) was higher than that of *Artocarpus heterophyllus* (102.24 kg·tree^{-1}·a^{-1}) or *A. hirsutus* (7.46 kg·tree^{-1}·a^{-1}) (Isaac and Nair 2006), other agroforestry species of the same family (Moraceae), thus contributing to high return of nutrients absorbed by tree roots from deeper soil layers to soil surface.

Litterfall followed a bimodal pattern of distribution. Maximum litterfall occurred during October-November, with total litterfall of 782.11 kg·ha^{-1} in October and 418.77 kg·ha^{-1} in November. Leaf litterfall was 700.61 kg·ha^{-1} in October and 303.56 kg·ha^{-1} in November (Fig. 1). Another peak was observed during January−February, when other litter components (354.39 kg·ha^{-1} in January and 202.89 kg·ha^{-1} in February) were greater. The single largest contribution to total litterfall was in October (22.27%). High litterfall coincided roughly with low rainfall months in Mandya during 2009−2010 (Fig. 1) and peak of litterfall may be associated with natural senescence of leaves induced by moisture stress and/or temperature in the region (Kumar and Deepu 1992). In tropical dry evergreen forests of South India, peak leaf litter production of *F. benghalensis* was observed in May (Pragasan and Parthasarathy 2005). However patterns of nutrient cycling in forest ecosystems might not be similar to trees managed in agroforestry systems: variations might be caused by management practices such as pruning and tillage (Nair 1993).

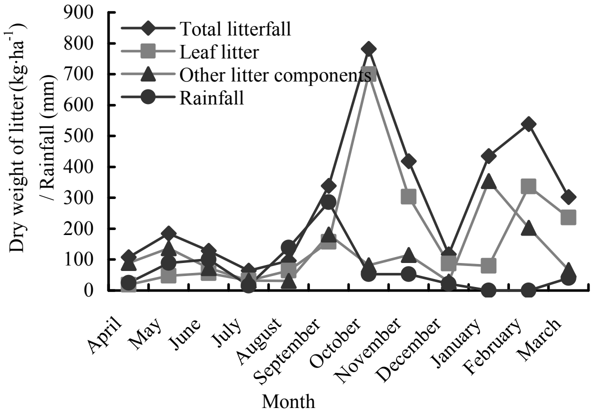

Fig. 1 Litterfall pattern of *Ficus benghalensis* trees in agroforestry systems of Mandya in relation to monthly rainfall. * Source of rainfall data: Mandya district at a glance (2009−2010).

An important implication of the litterfall pattern of *Ficus* in agroforestry systems is that the trees shed maximum leaves during the maturation phase of *kharif* (monsoon) crops thereby minimising competition with crops for resources (especially light) and complementing the existing cropping pattern. The synchrony of traditional agroforestry trees with cropping patterns has been well studied for species like *Faidherbia albida* (World Agroforestry Centre 2009). Leaf litterfall of *F. benghalensis* is minimal during peak summer months (March−June), enhancing its value as a fodder tree when other fodder resources are scarce. Litter production of *Ficus* showed distinct peaks but was continuous with regular nutrient inputs occurring in all months. This helps to maintain the productivity of dryland cropping systems.

Nutrient return through litter

Estimation of N, P and K concentrations of monthly leaf litter collected in litter traps showed a mean N content of 1.1(±0.26)%, P, 0.16(±0.07)% and K, 0.86(±0.23)% (standard deviation in parenthesis). Jamaludheen and Kumar (1999) classified tree species based on litter quality with litter of N content > 1.5% rated as high, 1%−1.5% as medium and < 1% as low. According to this classification, *F. benghalensis* could be classified as medium detritus N species. A distinct seasonal variation was discernible in N and P concentrations when the nutrient values declined during wet season (Fig. 2). This may be due to nutrient partitioning for more productive uses like wood or fruit formation during the wet season. Uniformly low values for N, P and K of litter samples during the wet season were documented by Khiewtam and Ramakrishnan (1993). No such trend was reported, however, for K, possibly due to species differences in the present study.

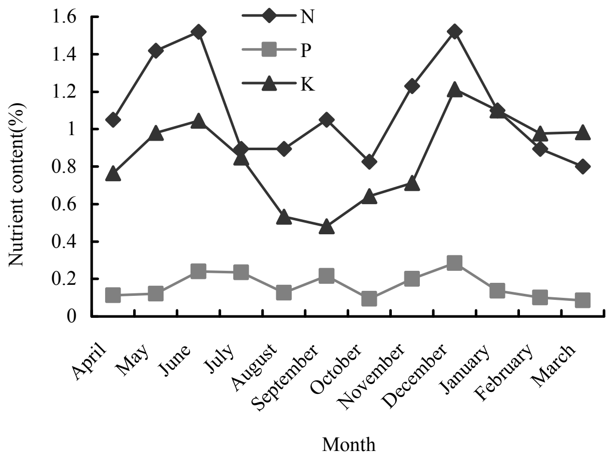

Fig. 2 Monthly variation in concentrations of major nutrients in *F. benghalensis* leaf litter. (Single factor ANOVA revealed that N concentration did not vary significantly between months, while P and K varied significantly at $p < 0.05$. F=3.72 and 5.8 and Fisher's Least Square Difference for comparing months= 0.125 and 0.336 respectively for P and K at $p < 0.05$).

Annual return of nutrients through litterfall was estimated by converting nutrient content to per ha values based on litter quantity. The nutrients returned were estimated to be 37 kg·ha^{-1} N; 8.58 kg·ha^{-1} P and K, 20.42 kg·ha^{-1} (Table 1). Among the major nutrients, N was the most important nutrient recycled through litter; K addition was appreciable but P was very low. The higher rate of nitrogen cycling in litter compared to other major nutrients has been well documented in other tree species (Saravanan et al. 1995; Nair et al. 1996; Isaac and Nair 2006). Litter nutri-

ents could have met 76.73% of N demand, 20.24% of P demand and 67.76% of K demand of dryland crops annually in Mandya if *Ficus* litter had been the sole source of nutrients (Table 1). This indicates the potential of this species to meet crop nutrient needs for farmers who are unable to afford expensive chemical fertilisers.

Table 1. Monetary evaluation of nutrient addition through *F. benghalensis* litterfall

Component	Quantity ($kg \cdot tree \cdot year^{-1}$)	N		P		K		Total
		%	$kg \cdot tree^{-1}$	%	$kg \cdot tree^{-1}$	%	$kg \cdot tree^{-1}$	
Leaf litter	132.53	1.10	1.46	0.16	0.22	0.86	1.14	
Others	86.96	0.98	0.85	0.37	0.32	0.16	0.14	
Total nutrient released on decomposition of litterfall ($kg \cdot ha^{-1} \cdot year^{-1}$ at average tree density of 16 ha^{-1})		37.00		8.58		20.42		
Average annual requirement of nutrients in drylands ($kg \cdot ha^{-1}$)*		48.22		42.42		30.13		
Percent demand met from *Ficus* litter		76.73		20.24		67.76		
Average expenditure incurred for crop nutrients *(US \$ $ha^{-1} \cdot a^{-1}$)		24.41		15.46		2.09		41.96
Additional cost to be incurred in absence of *Ficus* (US \$ $ha^{-1} \cdot a^{-1}$)		8.52		8.29		3.65		20.46
Additional cost as percentage of total fertiliser expenses								48.76

Notes: *Source: Farmer interviews.

Monetary values of litter nutrients computed using market prices of N, P and K in Mandya showed that in the absence of *Ficus* trees, farmers would have incurred additional cost of US\$ 20.46 $ha^{-1} \cdot a^{-1}$ to achieve equivalent yields and this would have increased their expenditure on inorganic fertilisers by 49% (Table 1). The opportunity cost of not having *Ficus* increases to US\$ 36.46 $ha^{-1} \cdot a^{-1}$, when transportation costs and labour costs for fertiliser application are added to nutrient input costs. *Ficus* litter nutrients are generated *in-situ* and do not require labour for application because litter is ploughed in during land preparation. Hence a total value of US \$36.46 $ha^{-1} \cdot a^{-1}$ can be imputed for nutrients returned to soil through *Ficus* litter addition. The value might be yet higher if secondary and micronutrients are included in the analysis.

Litter decomposition

Litter decomposition showed a rapid initial mass loss in the first 6-7 months after incubation, followed by a slower rate of loss from 8 to 12 months. A negative exponential model ($Y_t = Y_0 \times e^{-kx}$, where Y_0 is the initial proportion of litter mass applied and Y_t is the proportion of initial mass remaining after x months) best described the weight loss pattern of litter during decomposition (Fig. 3). Decomposition was faster in subsurface treatment, with only 22.5% of initial litter mass remaining after one year of incubation, while in surface treatment 28.3% of mass remained (Fig. 3). The decay constant of litter was slightly higher for subsurface treatment (0.125) than for surface treatment (0.107), indicating moderately faster decay in subsurface treatment. Half life periods of leaf litter ranged from 5.54 months in subsurface treatment to 6.48 months in surface treatment. This difference in decay rates between treatments was not significant. Litter incorporated in soil generally decomposes faster than surface material (Parker 1962; Read et al. 1985). The absence of significant difference in decay rates above and below the soil surface might have resulted from failure to place litter in direct contact with decomposers when litter was placed at shallow soil depths. Hence, for faster decomposition, deeper placement into the soil might be required. This suggests that *Ficus* litter must be ploughed deeply into the soil or separately composted before application on the field for faster decomposition and quicker nutrient release.

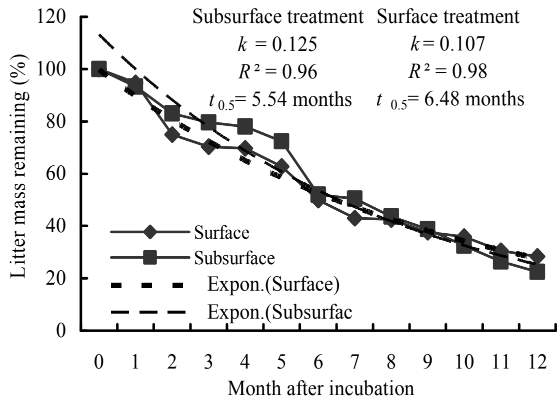

Fig. 3 Weight loss of litter (%) in two treatments during the course of incubation

The decay constant of *F. benghalensis* litter was lower than that reported for many tropical tree species by Jamaludheen and Kumar (1999), while the decomposition rate was faster than those for *F. glomerata* and *F. roxburghii* in the central Himalaya (Semwal et al. 2005). Differences in decomposition rates might be attributed to variations in litter quality (Waring and Schlesinger 1985) and climate and soil conditions (Mugendi and Nair 1997). Initial chemical analysis of litter revealed N content of 1.1%, lignin content of 30.50%, total phenolic content of 6.76%, C/N ratio of 23.89 and lignin/N ratio of 27.60. Litter with low lignin and phenols, and high nitrogen are generally considered good quality material for decomposition (Young 1997). Available literature suggest that plant materials with N <1.7%, lignin >15%, poly phenol >3% and C/N ratio >20 are of poor quality, they mineralise slowly, and immobilise N (Palm 1995; Oglesby

and Fownes 1992; Constantinides and Fownes 1994). Using these criteria, *F. benghalensis* litter can be considered low quality. Slow decay suggests that *Ficus* litter is efficient organic mulch which can cover the surface of dryland soils to prevent evaporative losses.. Also large quantities of slowly decomposing litter lead to higher soil organic matter and a larger pool of slow-release nutrients which might sustain crop productivity.

Conclusions

The pattern of litterfall and litter decay has important implications for exploiting *Ficus* as an agroforestry species in Mandya. In strongly seasonal climates, contribution of leaf litter to soil fertility through decomposition is determined by litter quality as well as the timing of litterfall (Semwal et al. 2005). *Ficus benghalensis* shows a bimodal pattern, with two bouts of heavy litterfall during October–November and January-February. The poor litter quality and low decomposition rates, however, ensure that nutrients from litter fall surges are released slowly and facilitate nutrient availability to crops throughout the year. This is a vital support mechanism for dryland farmers who are unable to afford the required amounts of chemical inputs. Also *Ficus* litter can be used as an effective mulch to prevent moisture loss from dryland soils due to its slow decomposition. Alternatively if farmers aim to quickly exploit the litter from *Ficus* trees to meet crop requirements, deep *in-situ* incorporation of litter into soils by ploughing is recommended for faster nutrient release.

The continuous litter inputs from *Ficus* help to maintain productivity of organic matter in deficient dryland soils. Further, maximum leaf shedding in October-November minimises competition for resources between *Ficus* trees and monsoon crops that mature during these months, while minimal leaf fall during summer ensures fodder availability for livestock when alternative sources are scarce. The litterfall pattern and litter decomposition of *Ficus* trees complement the cropping pattern in rainfed farmlands of Mandya and save input costs to farmers (valued at US$ 36.46 $ha^{-1}\cdot year^{-1}$). This might have a considerable bearing on the sustainability of the rainfed farming systems by reducing dependence on external inputs. Our findings emphasise the importance of recognizing in development policies, previously unquantified ecological services rendered by *Ficus* and/or similar native trees in traditional low-input agroforestry systems of semiarid zones.

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References

Anderson JM, Ingram JS. 1993. *Tropical Soil Biology and Fertility*: A Handbook of Methods (second edition). Wallingford, UK: CAB international, p. 221.

Constantinides M, Fownes JH. 1994. Nitrogen mineralization from leaves and litter of tropical plants: relationship to N, lignin and soluble polyphenol concentrations. *Soil Biology and Biochemistry*, **26**(1): 49−55.

Deb BAR, Arunachalam A, Arunachalam KS. 2008. Ecological analysis of traditional agroforest and tropical forest in the foothills of Indian Eastern Himalaya: Vegetation, soil and microbial biomass. *Tropical Ecology*, **49**(1): 73−78.

Dhanya B. 2011. Integrated study of a Ficus based traditional agroforestry system in Mandya district, Karnataka. Ph. D thesis. Dehradun, India; Forest Research Institute Deemed University, p. 211.

Dhanya B, Viswanath S, Purushothaman S, Suneeta B. 2010. *Ficus* trees as components of rainfed agrarian systems in Mandya district of Karnataka. *My Forest*, **46**(2): 161−165.

Isaac SR, Nair MA. 2006. Litter dynamics of six multipurpose trees in a homegarden in Southern Kerala, India. *Agroforestry Systems*, **67**: 203−213.

Jackson ML. 1973. *Soil Chemical Analysis*. New Delhi: Prentice Hall of India Pvt. Ltd., p. 1−125.

Jamaludheen R, Kumar BM. 1999. Litter of multipurpose trees in Kerala, India: Variations in the amount, quality, decay rates and release of nutrients. *Forest Ecology and Management*, **115**: 1−11.

Khiewtam RS, Ramakrishnan PS. 1993. Litter and fine root dynamics of a relict sacred groove forest at Cherrapunji in north eastern India. *Forest Ecology and Management*, **50**: 181−201.

Kumar BM, Deepu JK. 1992. Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Peninsular India. *Forest Ecology and Management*, **50**: 181−201.

Mubarak AR, Elbashir AA, Elamin LA, Daldoum DMA, Steffens D, Benckiser G. 2008. Decomposition and nutrient release from litter fall in the semi-arid tropics of Sudan. *Communications in Soil Science and Plant Analysis*, **39**: 2359–2377.

Mugendi DN, Nair PKR. 1997. Predicting the decomposition patterns of tree biomass in tropical highland microregions of Kenya. *Agroforestry Systems*, **35**: 187−201.

Nair MA, Abraham J, John J, Sanjeev V. 1996. Biomass productions and nutrient cycling for sustainability in agroforestry homegardens in Kerala –a case study. In: Proceedings of National Seminar on Organic Farming and Substantial Agriculture. Bangalore: University of Agricultural Sciences, pp 19−20.

Nair PKR. 1993. *Introduction to Agroforestry*. Dordrecht, The Netherlands: Kluwer, p. 499.

Oglesby KA, Fownes JH. 1992. Effects of chemical composition on nitrogen mineralisation of green manures of seven tropical leguminous trees. *Plant and Soil*, **143**: 127-132.

Palm CA. 1995. Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agroforestry Systems*, **30**: 105−124.

Parker DT. 1962. Decomposition in the field of buried and surface-applied corn stalk residues. *Soil Science Society of America Journal*, **26**: 559−562.

Pragasan LA, Parthasarathy N. 2005. Litter production in tropical dry evergreen forests of south India in relation to season, plant life forms and phys-

iognomic groups. *Current Science*, **88**(8): 125–126.

Proctor J. 1983. Tropical forest litterfall I. Problems of data comparison. In: S. L Sutton, T. C. Whitmore and A. C. Chadwick (eds), *Tropical Rain Forest: Ecology and Management*. Oxford, U. K: Blackwell Scientific Publications, pp. 287–309.

Read MD, Kang BT, Wilson GF. 1985. Use of *Leucaena leucocephala* (Lam.de Wit) leaves as nitrogen source for crop production. *Fertility Research*, **8**: 107–116.

Rowell RM, Pettersen R, Han JS, Rowell J, Tshabalala MA. 2005. Cellwall chemistry: In: R. M. Rowell (ed.), *Handbook of Wood Chemistry and Wood Composites*. USA: Taylor and Francis, CRC Press, p. 65.

Sadasivam S, Manickam A. 1992. *Biochemical Methods for Agricultural Sciences*. New Delhi: Wiley Eastern Limited and Coimbatore: Tamil Nadu Agricultural University, p. 246.

Saravanan A, Kalieswari RK, Nambeesan KMR, Sankaralingam P. 1995. Leaf litter accumulation and mineralisation pattern of hilly soils. *Madras Agricultural Journal*, **82**: 184–187.

Semwal RL, Maikhuri RK, Rao KS, Sen KK, Saxena KG. 2005. Leaf litter decomposition and nutrient release pattern of six multipurpose tree species of central Himalaya, India. *Biomass and Bioenergy*, **24**(1): 3–11.

Tanner EVJ, Kapos V. 1992. Nitrogen and phosphorus fertilisation effects on Venezuelan montane forest trunk growth and litterfall. *Ecology*, **73**: 78–86.

Waring RH, Schlesinger WH. 1985. *Forest Ecosystem*: *Concepts and Management*. New York: Academic Press, pp. 181–211.

World Agroforestry Centre. 2009. *Creating an Evergreen Agriculture in Africa for Food Security and Environmental Resilienc*e. Nairobi, Kenya: World Agroforestry Centre, p. 24.

Young A. 1997. *Agroforestry for Soil Management* (Second edition). New York, USA: CAB International and Nairobi, Kenya: International Centre for Research in Agroforestry, pp. 47–109.